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Report of a Joint FAO/WHO Expert Meeting, 3–7 September 2012, FAO Headquarters, Rome, Italy

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Acknowledgments

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DECLARATIONS OF INTEREST

All participants completed a Declaration of Interests form in advance of the meeting. None were considered to present any potential conflict of interest.

Abbreviations used in the report

CAC	Codex Alimentarius Commission
CCFH	Codex Committee on Food Hygiene
FAO	Food and Agriculture Organization of the United Nations
FERG	WHO Food-borne Disease Epidemiology Reference Group
GAP	Good Agricultural Practice
GHP	Good Hygiene Practice
HACCP	Hazard Analysis and Critical Control Points
OIE	World Organisation for Animal Health
WHO	World Health Organization

Executive Summary

At the 42nd Session (December 2010) of the Codex Committee on Food Hygiene (CCFH), the Committee requested that FAO and WHO

> "review the current status of knowledge on parasites in food and their public health and trade impact in order to provide CCFH with advice and guidance on the parasite-commodity combinations of particular concern, issues that need to be addressed by risk managers, and the options available to them."

On the basis of this information, CCFH would determine the feasibility of developing general guidance as a framework for annexes that would address specific parasite-commodity combinations.

To address this request FAO and WHO initiated a series of activities that culminated in an expert meeting on 3–7 September 2012. Preceding the meeting, relevant data were identified and collated through a formal "call-for-data" and by written reports from experts representing the African, Asian, Australian, European, Near Eastern, North American and South American Regions. Some 93 potential parasites were initially identified for consideration. Preliminary work was also undertaken on the development of a ranking tool and experts provided inputs to this through an on-line questionnaire. This preliminary ranking work combined with additional discussions during the meeting, resulted in a list of 24 parasites for ranking. Experts further identified specific vehicles of transmission for each of the 24 parasites.

It is important to note that food-borne parasitic diseases present some unique challenges, and are often referred to as neglected diseases. Notification to public health authorities is not compulsory for most parasitic diseases, and therefore official reports do not reflect the true prevalence or incidence of the disease occurrences (under-reporting). The parasites have complicated life cycles, which may include multiple hosts, some of which could become food, or the parasites themselves could contaminate food. The disease can present with prolonged incubation periods (up to several years), be sub-clinical or asymptomatic, and epidemiological studies associating illness with a specific food type may not be possible.

With technical guidance, the experts defined global criteria for evaluating the 24 food-borne parasites and rated each parasite along these criteria. The criteria can be summarized as: (1) number of global illnesses; (2) global distribution; (3) morbidity-acute; (4) morbidity-chronic; (5) percentage chronic; (6) mortality; (7) increasing illness potential; (8) trade relevance; and (9) socio-economic impact. Each criterion was then weighted by the experts in terms of their importance. The three criteria for disease severity (3, 4 and 5) were combined into one criterion, giving a total of 7 criteria weights, reflecting the relative importance of each criterion to the overall score. The overall score for each parasite was calculated by normalized parasite criteria scores multiplied by fractional weights, and summed.

The primary outputs of the expert meeting were the development of the ranking tool and the actual global ranking, based primarily on public health concerns, i.e. 85% of weighting. The global ranking of food-borne parasites by "importance" and their primary food vehicle in descending order was:

Taenia solium – Pork
Echinococcus granulosus – Fresh produce
Echinococcus multilocularis – Fresh produce
Toxoplasma gondii – Meat from small ruminants, pork, beef, game (red meat and organs)
Cryptosporidium spp. – Fresh produce, fruit juice, milk
Entamoeba histolytica – Fresh produce
Trichinella spiralis – Pork
Opisthorchiidae – Freshwater fish
Ascaris spp. – Fresh produce
Trypanosoma cruzi – Fruit juices
Giardia duodenalis – Fresh produce
Fasciola spp. – Fresh produce (aquatic plants)
Cyclospora cayetanensis – Berries, fresh produce
Paragonimus spp. – Freshwater crustaceans
Trichuris trichiura – Fresh produce
Trichinella spp. – Game meat (wild boar, crocodile, bear, walrus, etc.)
Anisakidae – Salt water fish, crustaceans, and cephalopods
Balantidium coli – Fresh produce
Taenia saginata – Beef
Toxocara spp. – Fresh produce
Sarcocystis spp. – Beef and pork
Heterophyidae – Fresh and brackish water fish
Diphyllobothriidae – Fresh and salt water fish
Spirometra spp. – Fish, reptiles and amphibians

This ranking should be considered a "snapshot" and representative only of the information available at the time, the criteria used for ranking, and the weightings assigned to those criteria. Also, some of these parasites had very similar rankings, so it might be more relevant to consider the parasites in groups of concern, e.g. top 5, or top 10, rather than the individual ranking position. With more information or with changing human and animal behaviour, and with climate change effects, parasite scoring and subsequent ranking could also change. As with many phases of risk analysis, it may be important to repeat and update the process on a regular basis. In fact, with heavily weighted public health criteria, the ranking results in part reflect risk defined as a function of the probability of an adverse health effect, and the severity of that effect consequential to a hazard in food. If the parasites are ranked only on trade criteria scores, the order of importance changes: *Trichinella spiralis*, *Taenia solium*, *Taenia saginata*, Anisakidae and *Cyclospora cayetanensis* are the top five. In this way, individual criteria can be considered, e.g. by CCFH, outside of the total scoring and weighting processes to assure that specific concerns can be addressed transparently and separately if needed.

Since criteria weights were calculated separately from the individual parasite scoring, alternative weighting schemes reflecting the judgments of risk managers could be used to generate alternative ranking, using the scoring of the parasites undertaken by the expert meeting. Thus, the ranking process that was developed was considered to be as important an output of the meeting as the ranking result, since it allows the global ranking to be updated through changes in scoring and to reflect the priorities of different groups of risk managers or stakeholders through different weighting. The process can be completely re-run at national or regional level using data more specific to that particular country or region.

Finally, the meeting also highlighted some considerations for risk management including possible approaches for the control of some of these food-borne parasites. Reference is also made to existing risk management texts as appropriate. This information, together with the global ranking of the parasites, the identification of the primary food vehicles and information on food attribution, is aimed to assist Codex in terms of establishing their priorities and determining the next steps in terms of managing these hazards. However, it should be noted that management of specific parasites may then require further scientific input, which it was not feasible to provide as part of this present process.

1

Background

Infectious diseases caused by food-borne parasites, generally defined as

> "Any organism that lives in or on another organism without benefiting the host organism; commonly refers to pathogens, most commonly in reference to protozoans and helminths."
>
> (CDC, NO DATE)

are often referred to as neglected diseases, and from the food safety perspective parasites have not received the same level of attention as other food-borne biological and chemical hazards. Nevertheless, they cause a high burden of disease in humans. The infections may have prolonged, severe, and sometimes, fatal outcomes, and result in considerable hardship in terms of food safety, security, quality of life, and negative impacts on livelihoods.

Food-borne parasites can be transmitted by ingesting fresh or processed foods that have been contaminated with the transmission stages (spores, cysts, oocysts, ova, larval and encysted stages) via the environment; by animals (often from their faeces); or by people (often due to inadequate hygiene). Food-borne parasites can also be transmitted through the consumption of raw and under-cooked or poorly processed meat and offal from domesticated animals, wild game and fish containing infective tissue stages (Slifko, Smith and Rose, 2000). Despite the fact that the parasite does not replicate outside a live host, food processing techniques in common use can artificially amplify the quantity of contaminated food that reaches the consumer, increasing the number of human cases (e.g. sausage made from meats of different origin).

Notification to public health authorities is not compulsory for most parasitic diseases, and therefore official reports do not reflect the true prevalence or incidence of the disease (under-reporting) that occurs. Although the global impact of food-borne diseases on public health is largely unknown due to limited data, the burden of disease caused by some parasites has been estimated by the WHO Food-borne Disease Epidemiology Reference Group (FERG). FERG (Fürst, Keiser and Utzinger, 2012) assessed the global burden of human food-borne trematodiasis with data for the year 2005, and estimated that 56.2 million people were infected by food-borne trematodes, of which 7.8 million suffered from severe sequelae and 7158 died worldwide. This and other FERG papers include individual parasites and country data, as well as disability calculations, but reports do not routinely provide food attribution data.

The complexities of the epidemiology and life cycle of each parasite play a central role in the identification, prevention and control of the risks associated with food-borne parasitic diseases. Surveillance for parasitic diseases is complicated by the often prolonged incubation periods, sub-clinical nature and unrecognized, chronic sequelae. The spread of food-borne parasitic diseases is enhanced by changes in human behaviour, demographics, environment, climate, land use and trade, among other drivers. (Orlandi *et al.*, 2002; Macpherson, 2005; Broglia and Kapel, 2011). Some examples worth mentioning in the context of this report are the globalization of food trade, which offers new opportunities for dissemination; variations in food preferences and consumption patterns, such as the expected global increase in meat consumption in emerging countries over the next 20 years; the increasing tendency to eat meat, fish or seafood raw, under-cooked, smoked, pickled or dried; or the demand for exotic foods such as bush meat or wild game. The impact of climate change on parasite life cycles in the environment will depend on several factors, such as the number of hosts (one, two or more) involved in the transmission, the presence or absence of intermediate hosts or vectors, free living stages[1] and reservoir host species (Mas-Coma, Valero and Bargues, 2009; Polley and Thompson, 2009). The potential for climate change could affect parasite host(s) habitats, present a greater likelihood of contamination due to extreme weather events, and create increased pressure on some food sources (Davidson *et al.,* 2011).

Options for control of some parasites that can cause human and zoonotic diseases have been addressed collaboratively by FAO, WHO and the World Organisation for Animal Health (OIE). Extensive guidelines for the surveillance, management, prevention and control of taeniosis/cysticercosis and trichinellosis have been published in 2005 and 2007, respectively, and OIE is currently revising the chapter in the *Terrestrial Animal Health Code* for *Trichinella* spp., *Echinococcus granulosus*

[1] For the purposes of food-borne animal parasite discussions, a free-living stage is a stage of a parasite that lives outside of its host or hosts (Rohr *et al.*, 2011).

and *Echinococcus multilocularis*. Aquaculture product standards are addressed by the Codex Alimentarius Commission (CAC) and the FAO Fisheries and Aquaculture Department. EU directives for food-borne parasites already exist. However, increased multidisciplinary collaboration is needed for risk-based prevention and control of parasites at all stages of the production-to-consumption continuum. Such control is necessary to safeguard public health and minimize production problems and economic losses caused by parasites.

One of the CAC committees, the Codex Committee on Food Hygiene (CCFH), is currently developing "Guidelines for the Control of Specific Zoonotic Parasites in Meat: *Trichinella spiralis* and *Cysticercus bovis*[2]", working in close cooperation with OIE. In undertaking this work the Committee recognized the need to address food-borne parasites more broadly, based on their risk to human health as well as their socio-economic and trade impacts, and, if needed, to provide more general guidance for their control. Therefore, at its 42nd Session (December 2010) the Committee requested that FAO and WHO

> "review the current status of knowledge on parasites in food and their public health and trade impact in order to provide the CCFH with advice and guidance on the parasite-commodity combinations of particular concern, the issues that need to be addressed by risk managers, and the options available to them."

On the basis of this information, CCFH would evaluate the feasibility of developing a general guidance document that would provide a framework where annexes could address specific parasite×commodity combinations. FAO and WHO convened an Expert Meeting on Food-borne Parasites on 3–7 September 2012 at FAO Headquarters, Rome, Italy, to respond to the request of the CCFH.

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2 Clarification note to the CCFH: During the expert meeting, the more precise taxonomic term *Taenia saginata* was used instead of the older and less formal designation, *Cysticercus bovis.* The human disease is taeniasis due to the tapeworm form, while the cattle disease is cysticercosis due to the metacestode (cysticercus) form (Flisser, Craig and Ito, 2011).

2

Objectives and approach

The objectives of the meeting were as follows:

- To develop a ranked list of food-borne parasites of global importance.
- To identify the foods of greatest concern for the most important food-borne parasites.
- To provide an overview of the risk management options and approaches available for the control of the most highly ranked food-borne parasites.

A systematic, evidence-based approach was taken to prioritize the food-borne parasites of global importance. An expert-based, multicriteria ranking tool was designed, and implemented during the meeting. It built on data gathered in advance of the meeting by means of an FAO/WHO formal "call for data" and through electronic working procedures facilitated by the FAO/WHO Secretariat. Additional data came from detailed presentations at the meeting itself. Results of this ranking exercise achieved the first objective and informed systematic discussions to address the second and third objectives.

The meeting was attended by 21 internationally recognized experts in food-borne parasites from 20 countries covering all global regions, together with 9 resource people and the FAO/WHO secretariat, as well as additional resource people from FAO and WHO (see list of Contributors in the front matter). The expert meeting was chaired by Dr Joke van der Giessen, Dr Brent Dixon served as Vice-Chair and Dr Rebecca Traub served as Rapporteur.

The process used to rank food-borne parasites and identify risk management strategies is shown in Figure 1. The process comprised 6 primary steps: (1) Identification of parasites for ranking; (2) Identification of key foods of concern for each parasite; (3) Identification and definition of criteria by which each parasite would be evaluated; (4) Expert scoring of each parasite based on the criteria; (5) Weight importance of each criterion in overall parasite scoring; and (6) Calculation of parasite scores and subsequent ranking. As shown in the figure, some steps can be further broken down into stages, many of which began prior to the meeting. The figure also shows which activities in the process were primarily conducted by the FAO/WHO secretariat and which were done entirely by experts or by experts with FAO/WHO facilitation.

The expert-based parasite ranking exercise was developed following a multicriteria assessment (MCA) approach. It was specifically based on a number of similar assessments conducted for zoonotic and infectious diseases in the past few years (e.g. Anderson *et al.*, 2011; Cardoen *et al.*, 2009; Havelaar *et al.*, 2010; Humblet *et al.*, 2012; Krause *et al.*, 2008; Ng and Sargeant, 2012). Most of these ranking approaches follow a similar multicriteria approach in which a set of hazards are evaluated with a set of criteria, including but not limited to public health, and then overall scores are computed based on a weighting of those criteria. There is no standard methodology for conducting a multicriteria assessment, however, as such ranking exercises are designed for specific risk management contexts, they are inevitably constrained by resources, time and data availability.

The multicriteria-based ranking process included a number of efforts to collect, collate and share data and acquired knowledge. Published information was collected from the peer reviewed literature. This included the publications from the FERG Parasitic Diseases Task Force, FAO/WHO/OIE guidelines and others.

In the 2011 call for data, FAO and WHO requested information on (1) impact of food-borne parasitic diseases; (1A) impact on public health and (1B) socio-economic impact; (2) monitoring and inspection systems; (3) control and management; (4) risk assessment and risk profiles; and (5) risk ranking. Twenty-two member countries and one regional body (EU) responded. Results showed that most had adopted surveillance systems for food-borne parasitic diseases (n=20); monitoring and inspection systems for food-borne parasites (n=15); and appropriate control and management measures (n=15). However, data or information, or both, on socio-economic impact, were very limited, as were risk assessments, profiles and ranking. Most of the respondents recognized that T*richinella, Cryptosporidium, Echinococcus, Giardia, Toxoplasma* and *Taenia* were important as food-borne pathogens.

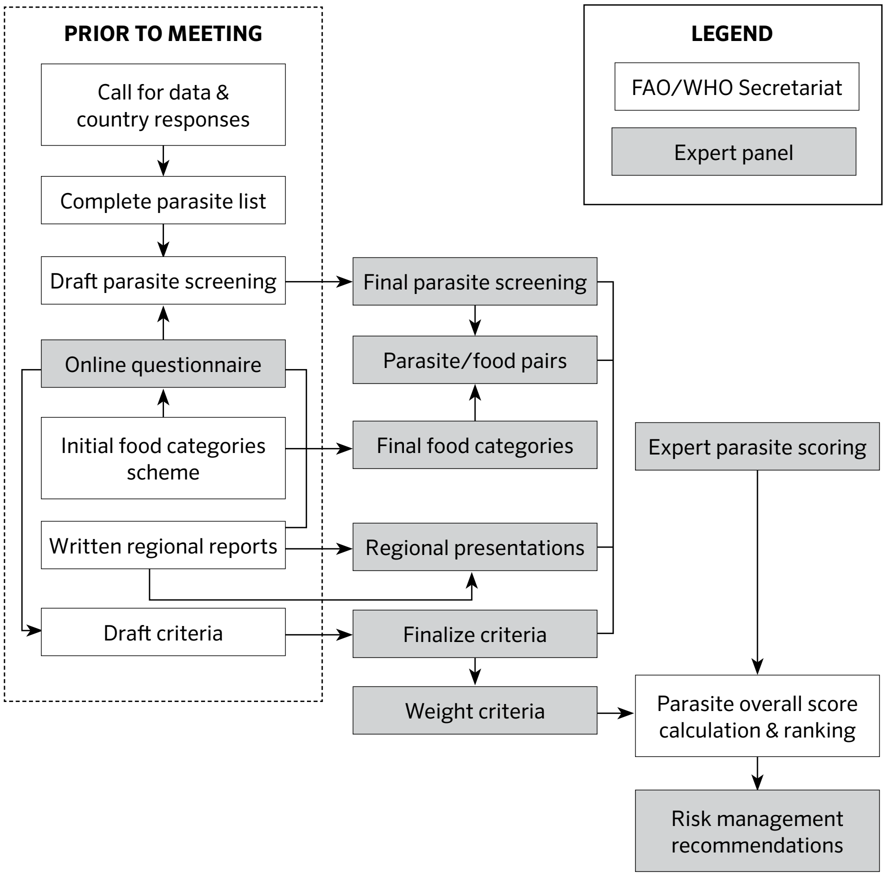

FIGURE 1. Flow chart of the multicriteria ranking exercise

Written reports were produced in advance of the meeting for each of seven geographic regions: Africa, Asia, Pacific (only included Australia), Europe, Near East, North America and South America. Presentations based on these reports were made by the experts at the meeting. The regional reports considered the current overall quantity and quality of data at the regional and global levels; burden of disease and food attribution; data on parasite prevalence, incidence and concentration in the main food categories; agri-food trade; consumer perception; social sensitivity; and risk management options. These reports were used by the experts in their deliberations during the meeting (see Annex 8 of this report).

An online questionnaire was sent to the 21 experts to examine the importance of criteria by which parasites might be evaluated and to elicit experts' initial judgments on the global and regional importance of each of 93 parasites. The questionnaire also captured information about the background and expertise of each expert.

2.1 IDENTIFICATION OF PARASITES

Following a "call for data" (July 2011) and input from experts, a comprehensive list of 93 parasites was created. This list was intended to capture the global set of human parasites for which consumption of food may be a relevant pathway.

An online questionnaire (July 2012) was sent to experts and each expert was asked to score the global and regional importance of each parasite from "not important" to "very important." It was decided that scoring 93 parasites was beyond the scope of the meeting, so results from these scores were used to create a three-tiered initial prioritization of parasites (Table A1 in Annex 1).

This initial prioritization was then used by experts in a screening exercise conducted at the meeting. Led by the Chair and Vice-Chair, experts reduced the parasite list by using inclusion and exclusion criteria. First, parasites were grouped by species or genera (Table A1.2 in Annex 1); then, where applicable, based on common transmission routes, clinical manifestations and attributable food-borne sources. Parasites were excluded when the proportion of food-borne illnesses was negligible or when parasites were only relevant in a limited geographic area (Table A1.3 in Annex 1). The result was a final list of 24 parasites to be ranked.

2.2 DEFINITION OF PRIMARY AND SECONDARY PARASITE AND FOOD PATHWAYS

In order to characterize primary food-borne pathways for key parasites, an eight-category food scheme was developed and incorporated into regional written reports generated by experts prior to the meeting. In their reports, experts identified specific foods within these categories and provided references to support food associations. These categories were created to capture both food animal reservoirs and hosts, as well as foods contaminated within the food chain (such as produce contaminated by water).

Following discussion at the meeting, consensus was reached among the experts on a food scheme comprising five broad categories (land animals; aquatic animals; dairy products; plants; and other) and seventeen sub-categories. This scheme is shown in Table 1.

This scheme was then applied to each of the 24 parasites, and used to identify the primary food vehicles associated with each parasite. For some parasites, secondary food vehicles were also defined, as shown in Table 2.

TABLE 1. Food category scheme

Food category	Food subcategory
Land animals	Beef
	Pork
	Poultry
	Small ruminants
	Other meat
	Game and wild animals
Aquatic animals	Marine fish
	Freshwater fish
	Shellfish
	Aquatic mammals
Dairy products	Dairy products
Plants	Berries
	Fruit juices
	Other fruit
	Leafy greens
	Other vegetables
	Fresh produce (refers to 2 or more of the above)
Other	Other foods

2.3 DEFINITION OF CRITERIA FOR PARASITE SCORING

Based on previous prioritization studies and risk management needs, five categories were considered for the analysis: public health, microbial ecology, animal health, agribusiness and trade, and socio-economic impact. A number of potential criteria in these categories were included in the online questionnaire to appraise the applicability of these criteria and to elicit experts' judgment on which criteria were more important. This information was used to generate an expansive list of 41 potential criteria in these five categories.

The FAO/WHO Secretariat narrowed the list of potential criteria to 11 and presented these to the experts at the meeting. Following extensive discussions on the list of criteria, consensus was reached on a final list of 9 criteria. Of these criteria, 5 relate to the quantity and severity of global disease, while two others relate to the global distribution of these illnesses and the potential for short-term emergence of increased disease. The remaining two criteria relate to the potential for the parasite (in its primary and secondary foods, defined previously) to affect trade, and the impact of the parasite on economically vulnerable communities.

TABLE 2. Parasites and main food vehicles

Parasites	Primary food category	Primary food vehicles	Secondary food vehicles	Global food attribution (1)
Anisakidae	Aquatic animals	Marine fish, crustaceans and cephalopods		All food-borne (fish).
Ascaris spp.	Plants	Fresh produce		Food-borne association but proportion unknown Mainly soilborne (geophagic). Multiple exposure routes in endemic areas. (2)
Balantidium coli	Plants	Fresh produce		Food-borne association but proportion unknown.
Cryptosporidium spp.	Plants	Fresh produce, fruit juice, milk		Food-borne association but proportion unknown (Estimated to be 8% in USA (Scallan *et al*,, 2011). Food-borne outbreaks documented. Water may be most important route.
Cyclospora cayetanensis	Plants	Berries, fresh produce		Mostly food-borne, e.g. basil, berries, lettuce, etc.
Diphyllobothriidae	Aquatic animals	Fish (freshwater and marine)		All food-borne.
Echinococcus granulosus	Plants	Fresh produce		Food-borne association but proportion unknown.(3)
Echinococcus multi-locularis	Plants	Fresh produce		Food-borne association but proportion unknown. Epidemiological risk surveys suggest food is not major transmission route.(4)
Entamoeba histolytica (Older studies did not distinguish Entamoeba *histolytica* from *E. dispar.*)	Plants	Fresh produce		Food-borne association but proportion unknown. Waterborne route important. Hygiene and food handlers often implicated.
Fasciola spp.	Plants	Fresh produce (aquatic plants)		Mainly food-borne through aquatic plants. Outbreaks reported.
Giardia duodenalis (syn. G. *intestinalis*, *G. lamblia*)	Plants	Fresh produce	Molluscan shellfish	Food-borne association but proportion unknown. Food-borne outbreaks documented. Handlers and multiple food types implicated (Christmas pudding, etc.). Water-borne outbreaks reported.
Heterophyidae	Aquatic animals	Fresh- and brackish-water fish		All food-borne (fish).
Opisthorchiidae	Aquatic animals	Freshwater fish		All food-borne (fish).

Parasites	Primary food category	Primary food vehicles	Secondary food vehicles	Global food attribution [1]
Paragonimus spp.	Aquatic animals	Freshwater crustacea		All food-borne.
Sarcocystis spp.	Land animals	Beef	Pork	All food-borne for S. suihominis and S. bovihominis
Sparganosis – *Spirometra* spp.	Other	Frog, snake meat		All food-borne
Taenia saginata	Land animals	Beef		All food-borne. Taeniosis exclusively meatborne.
Taenia solium	Land animals	Pork		Taeniosis exclusively meatborne.
	Plants (cysticercosis)	Fresh produce		Food-borne association but proportion unknown. Cysticercosis mainly soilborne; contaminated plants may be significant in some regions.
Toxocara spp.	Plants	Fresh produce		Food-borne association but proportion unknown. Mainly soilborne (geophagy).
Toxoplasma gondii	Land animals	Meat from small ruminants, pork, beef, game meat (red meat and organs)	Fresh produce, seafood, dairy products	Food-borne association (fresh produce) but proportion unknown. Multiple routes of infection, but transmission through meat is important. (Meatborne *Toxoplasma* infections estimated to be 22% in USA, Boyer *et al.*, 2011; 53% in Chile, Muñoz *et al.*, 2010; 26% in Colombia, López *et al.*, 2005) Waterborne outbreaks documented.
Trichinella spiralis	Land animals	Pork	Horse, Game meat	Exclusively meatborne. Making sausage or similar food products increases the risk to the consumer from a single animal.
Trichinella spp. (other than *Trichinella spiralis*)	Land animals	Game meat [5]	Pork	Exclusively meatborne.
Trichuris trichiura	Plants	Fresh produce		Food-borne association but proportion unknown. Mainly soilborne.
Trypanosoma cruzi	Plants	Fruit juices		Food-borne outbreaks documented. Fruit juice in limited geographic area. Mainly transmitted by insects

Notes: (1) The information in this column is based on peer reviewed publications in the scientific literature, unpublished reports and expert opinion, which may be the only approach to estimate food attribution for some of the parasitic diseases on a global basis. (2) Ascaris spp. eggs can become ubiquitous in an endemic area, making attribution difficult if not impossible. (3) The incubation period for *Echinococcus granulosus* can be as long as 5 to 15 years; it is not possible to precisely identify an exposure occurring many years previously. However, there are many articles indicating that E. granulosus eggs contaminate plants, and evidence that people in the endemic, developing countries consume vegetables, including raw. It is almost impossible to pinpoint the food source because the transmission routes are varied (e.g. contact with dog, other canids (fox, wolf), soil, etc.). (4) The incubation period for Echinococcus multilocularis can be 5–15 years, and the disease, alveolar echinococcus, is diagnosed at an advanced stage; it is not possible to precisely identify an exposure occurring many years previously. (5) Wild boar, crocodile, bear, walrus, etc.

The final criteria selected for scoring were: (1) Number of global food-borne illnesses (manifesting disease); (2) Global distribution (number of regions); (3) Acute morbidity severity (disability weight); (4) Chronic morbidity severity (disability weight); (5) Fraction of illness that is chronic (%); (6) Case-fatality ratio (%); (7) Likelihood of increased human burden (%); (8) How relevant is this parasite-food pathway for international trade?; and (9) What is the scope of the impact on economically vulnerable communities?

For each of these 9 criteria, between three and five scoring levels were defined. For 7 criteria, these scoring levels were defined quantitatively, while the remaining two were qualitative. Scoring levels were intended to allow for appropriate differentiation among the 24 parasites. These criteria, along with a question pertaining to data quality, are shown in Annex 2. Note that question 8, on international trade concerns, relates specifically to the pathogen in its primary food vehicle, whereas all other questions refer to the parasite in general.

2.4 SCORING PARASITES ACCORDING TO CRITERIA

Experts were divided into five groups of 4 to 5 people, organized so that each group had, to the extent possible, coverage across regions and expertise. Each group was given three documents: a summary card form for each parasite (see Annex 2), a document explaining each criterion and how to score it (Annex 3), and a list of parasites. The lists of parasites provided to each group were staggered in order to maintain equal numbers of scores across parasites, because all groups were unlikely to complete summary cards for all 24 parasites.

Each group used available material, such as regional written reports, published literature and WHO material on disability weights, coupled with online searches, to facilitate a discussion of each criterion for each parasite. Each group scored a summary card for each parasite on their list. Preliminary criteria scores were tabulated into spreadsheets for each group, and preliminary scores were presented back to the group. Discussions around large disparities in preliminary scores allowed the group to identify some differences in interpreting criteria. Once the expert panel reached consensus and greater clarity and agreement on criteria definitions, groups re-convened to review their scores. Following a second tabulation of preliminary results and similar discussion on criteria definitions, a third round of scoring was conducted to obtain final group parasite criteria scores.

Ultimately, two groups scored all 24 parasites and the remaining groups scored 21, 18 and 14 parasites respectively. Thus, 11 parasites had 5 sets of criteria scores, 7 parasites had 4 sets of scores, and 6 parasites had 3 sets of scores.

2.5 DEFINITION OF CRITERIA WEIGHTS

In multicriteria assessment, individual criterion scores are combined into an overall score for each parasite. In this instance, each criterion score was first normalized to a 0–1 scale, with equal divisions among levels. To combine these criteria scores, each criterion was weighted as a fraction of the total score, with all weights summing to 100%.

TABLE 3. Mean of elicited criteria weights used in the multi-criteria ranking.

Scoring criterion		Criterion weight
W1.	Number of global food-borne illnesses	0.22
W2.	Global distribution	0.14
W345.	Morbidity severity	0.22
W6.	Case-fatality ratio	0.15
W7.	Increasing illness potential	0.07
W8.	Trade relevance	0.10
W9.	Impacts on economically vulnerable communities	0.10

In this approach, each criterion is assigned its own weight, though in this case, three criteria relating to the severity of disease morbidity were combined (3, severity weight for acute disease; 4, severity weight for chronic disease; and 5, fraction of disease that is chronic) into a single adjusted criterion. Details are explained in the next section, but this combination resulted in requiring a single weight for morbidity severity, shown in Table 3 as W345. Thus, although there are 9 criteria used to compute the overall score for each parasite, there are only 7 criteria weights.

A worksheet (Annex 4) was given to each group and to six from the FAO/WHO Secretariat. Table 3 presents the mean criteria weights across all participants.

Criteria weights reflect the relative importance of the individual criterion in the overall score. Table 3 shows that public health criteria had most influence on the outcome of the ranking, accounting for 80% of the total weights agreed by experts. In particular, disease severity (morbidity severity and case-fatality ratio) accounted for 39% of the total score. These average expert criteria weights were incorporated into the ranking model.

Because criteria weights are calculated separately from individual parasite scoring, alternative weighting schemes reflecting the judgments of risk managers or stakeholders could be used to generate alternative rankings that nevertheless are based on expert parasite criteria scores.

2.6 CALCULATION OF PARASITE SCORES

The overall score for each parasite is given by the following equation:

$$Score = C1*W1+C2*W2+\{C3*(1-C5)+C4*C5\}*W345+C6*W6+C7*W7+C8*W8+C9*W9$$

where C are parasite-specific normalized criteria scores and W are constant criteria weights that are the same for all parasites. Criteria 3, 4 and 5 are combined to produce a single morbidity criteria; it is essentially the weighted average of acute and chronic disease severity. Thus, criteria 3, 4 and 5 have one associated weight, denoted in the equation as W345. Otherwise the calculation is straightforward: normalized parasite criteria scores are multiplied by fractional weights, and summed. Overall scores therefore range from 0 to 1.

A spreadsheet model was developed to calculate overall scores for each parasite based on all group summary cards and averaged criteria weights. The resulting scores were then ranked to produce the current list of global food-borne parasites.

3

Results

3.1 THE GLOBAL RANKING OF FOOD-BORNE PARASITES

The results of the ranking exercise, where the top ranking parasites are arranged on the x-axis from left to right in decreasing rank order and the average weights (in percentage) on the y-axis, are presented in Figure 2. This figure was obtained from the average of all elicited weights for the criteria. Among the top ranked parasites are those that have already been singled out by WHO as neglected tropical diseases (NTD), and identified by FERG as priorities for further burden of illness studies.

As noted in Chapter 2, this ranking is a combination of scoring the parasites based on predefined criteria and weighting the criteria based on the importance assigned to them by the expert meeting participants. Since many of the criteria were public health related, there were not big differences between the final ranking and the outcome of the scoring exercise alone, where all criteria are considered to have equal weight. Sensitivity analysis was carried out using alternative criteria weighting schemes (see Annex 5). Figure A5.3 in Annex 5 compares the ranks for global foodborne parasites scored across alternative criteria weighting schemes. Figure A5.5 in Annex 5 presents the scores for the public health criteria only, weighted equally, compared with baseline ranking based on all criteria and elicited weights. These figures are included for reference and indicate that the top 4 parasites remain the same based on expert scoring. It is also interesting to note that the gradually declining trend along the x-axis from left to right remains generally the same. Therefore the weighting of criteria did not radically change the ranks,

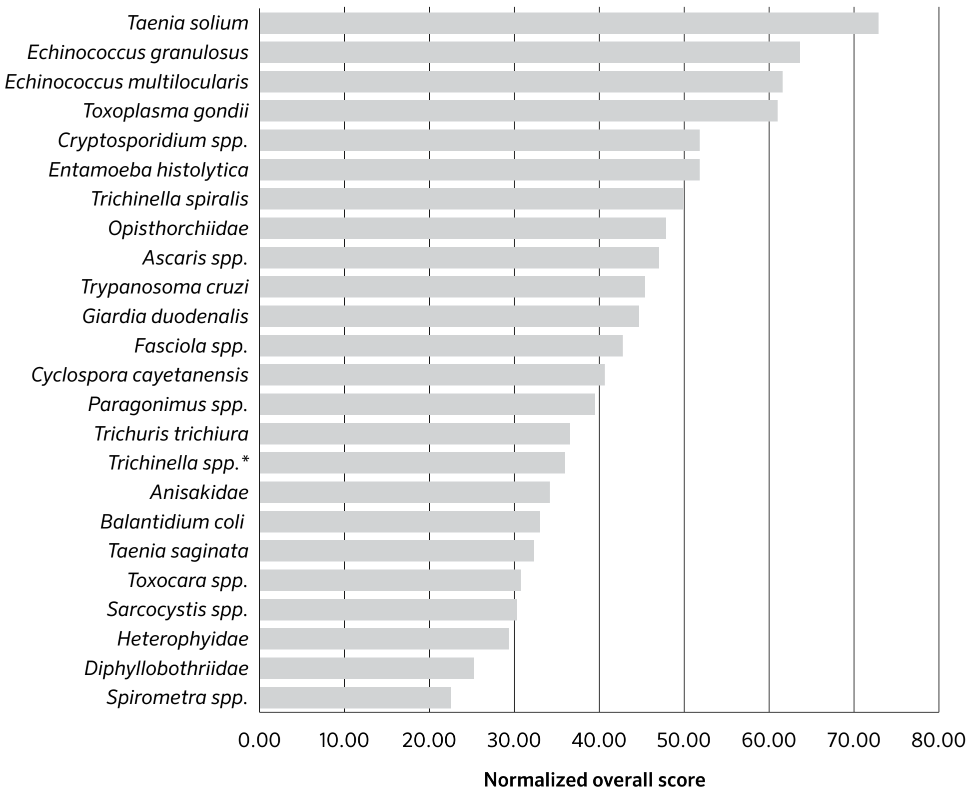

FIGURE 2. Global ranking of food-borne parasites using a multicriteria ranking tool for scoring parasites, with weighting of scoring criteria based on criteria scores and weights elicited from expert meeting participants (Note: *Trichinella* spp.* includes *Trichinella* species except T. *spiralis*).

and the public health criteria alone were not so different from the expert ranking. This also reflects the dominance of public health-related criteria in the ranking tool.

A short overview of the top 8 parasites in the above ranking is provided below. Further information relevant to the management of these parasites is provided in Chapter 4. As risk managers consider individual parasites, there will be a need to go into more depth for each. Specific information on the 24 ranked parasites was generated after the meeting and can be found in Annex 7.

Taenia solium

Taenia solium (ranked 1st in Figure 2) is estimated to infect millions of persons worldwide. It is unique in that the larval or cysticercus stage can infect humans as well as pigs, and can cause a wide range of debilitating neurological problems, including epilepsy. Human cysticercosis often occurs in areas where traditional pig husbandry is practiced, and is endemic in the Andean area of South America, Brazil, Central America and Mexico, China, India, Southeast Asia, and sub-Saharan Africa. The disease can be spread by poor sanitation and hygiene and improper slaughterhouse services. Human neurocysticercosis is increasingly being reported in developed countries, possibly due to increases in globalization and immigration (Carabin *et al*., 2011).

Echinococcus granulosus and *E. multilocularis*

In a recent report on neglected tropical diseases, scientists stated for *Echinococcus granulosus* and *E. multilocularis* (ranked 2nd and 3rd in Figure 2):

> "The diseases caused by these parasites represent a substantial burden on the human population. Present estimates suggest that cystic hydatid disease, caused by *Echinococcus granulosus*, results in the loss of 1 to 3 million disability-adjusted life years per annum. The annual cost of treating cases and economic losses to the livestock industry probably amount to US$ 2 billion. Alveolar echinococcosis, caused by *E. multilocularis,* results in the loss of about 650 000 disability-adjusted life years per year. These diseases are perhaps some of the more important global parasitic diseases, with more than 1 million people affected at any one time, many showing severe clinical syndromes."
>
> (WHO, 2011)

Toxoplasma gondii

Toxoplasma gondii is capable of infecting virtually all warm blooded animals, including humans. It has been estimated that close to 30% of the world population may be infected by *Toxoplasma gondii*. Pregnant women and immunocompromised individuals are the main risk groups, although immune-competent persons may develop ocular disease as a result of an infection later on in life. Furthermore, *T. gondii* infection has been associated with behavioural changes and development of psychiatric disorders. The parasite may be transmitted trans-placentally to the foetus when T. *gondii* infections occur during pregnancy. This can result in foetal death, central nervous system abnormalities or eye disease, affecting the child throughout its lifetime. The two routes of food-borne infection—via tissue cysts in various types of meat or organs, or via oocysts contaminating a wide range of food vehicles—makes transmission control a challenge.

Cryptosporidium spp.

The importance of *Cryptosporidium* spp. as a food-borne parasite has emerged in part through outbreak investigations that have linked fresh produce, fruit juice and dairy products with disease. In the USA, it is estimated that 8% of the annual food-borne disease burden may be attributed to this parasite. For most people, symptomatic cryptosporidiosis is characterized by acute watery diarrhoea, often accompanied by abdominal pain, nausea or vomiting, low grade fever, headache and general malaise. Most patients recover within 2–3 weeks, but highly immunocompromised patients may suffer chronic illness, also leading to severe disease and sometimes death. For most parasitic infections there is some treatment available, but for *Cryptosporidium* spp. infections in the immunocompromised, there is none. There is also increasing evidence that cryptosporidiosis may have long-term effects, such as chronic gastrointestinal conditions. In addition, it is noted that cryptosporidium oocysts are very resistant to chlorine commonly used to treat water.

Entamoeba histolytica

Entamoeba histolytica, as with *Cryptosporidium* spp., is probably primarily transmitted through food handlers and contaminated water, which can enter the food chain causing illnesses attributed to fresh produce; it should be noted that, unlike some *Cryptosporidium* spp., *E. histolytica* is not zoonotic. Amoebiasis is traditionally limited to dysenteric-like symptoms, with abdominal pain, bloody or mucoid diarrhoea, and tenesmus, but has the ability to invade extra-intestinal tissues also, e.g. inducing liver abscesses, and extra-hepatic spread of E. histolytica is associated with relatively high mortality (20–75%). One of the problems with its detection is that microscopy methods used for E. histolytica do not differentiate it from non-pathogenic species. This parasitic disease is of importance globally, but occurs predominately in developing countries and may be transmitted with immigrant populations to developed areas. Unlike *Cryptosporidium* spp., *E. histolytica* is susceptible to chlorine.

Trichinella spiralis

Trichinella spiralis, like all *Trichinella* species, has a unique lifecycle in that there is no environmental transmission stage – thus all cases are due to ingestion of meat containing the encysted larvae; meat types typically associated with *T. spiralis* include pork, horse meat, and game. Globally, there were 65 818 human infections reported between 1986 and 2009, with most of these reported for hospitalized patients in Romania, where 42 patient deaths were reported. However, there may be increased exposure through human behavioural trends, e.g. consumption of raw horse meat, dog meat, wild boar, and other sylvatic animal meats, as well as practices of free-range animal husbandry (infected animals are asymptomatic).

Opisthorchiidae

The Opisthorchiidae family includes various digenean parasites, of which the most medically important are *Clonorchis sinensis, Opisthorchis viverrini* and *Opisthorchis* *felineus.* All are transmitted to humans via ingestion of the encysted metacercaria in the flesh or skin of freshwater fish. Opisthorchiasis/clonorchiasis occurs autochthonously in southeast Asia, eastern Europe, and central Asia. FERG reported over 8 million infections globally in 2005, almost all of which occurred in southeast Asia, where over 300 000 people were heavily infected and 1323 died. Disability-adjusted life years was 74 367. The FERG report further states that awareness of this food-borne problem is limited; only Japan and South Korea have established successful control programmes for fish-borne trematodiases. Opisthorchiasis is particularly worrisome in its potential to be carcinogenic; case-control studies have suggested that a substantial proportion of cholangiocarcinoma in some Asian countries can be due to infection with *O. viverrini*.

Summary

The fact that this is a global ranking may mean that some diseases that are severe and often fatal, but limited to a particular region, are not highly ranked. One example is Chagas disease, transmission of which is at present largely restricted to parts of Central and South America, with FERG reporting over 11 000 deaths due to T*rypanosoma cruzi* worldwide in 2004. However, survival of the trypomastigotes in fruits and juices might present an unknown risk for global dissemination in the world market.

The parasites currently being considered by the CCFH were ranked seventh (*T. spiralis*) and nineteenth (*T. saginata/C. bovis*) for overall importance by the experts.

3.2 TRADE SCORES FOR THE RANKED PARASITES

The data used to rank parasites and generate Figure 2 are used to produce Figure 3, in which only the average trade criteria scores for each parasite are displayed. This figure suggests that there may be additional or separate trade issues that could be considered by risk managers such as Codex and national food authorities.

The parasites currently contemplated by the CCFH, *T. spiralis* and *T saginata/C. bovis,* were considered among the most important for trade, based on criteria scores. In the regional reports, *Trichinella spiralis, Taenia saginata, Taenia solium* and/or *Echinococcus granulosus* were mentioned as current or potential trade concerns in the African, Australian, European, Near Eastern and South American Regions. The North American and Asian Regions did not address this issue directly.

It may be of interest to risk managers that the Anisakidae that ranked lower (17th) in overall importance, scored higher for the trade criteria, and were mentioned in

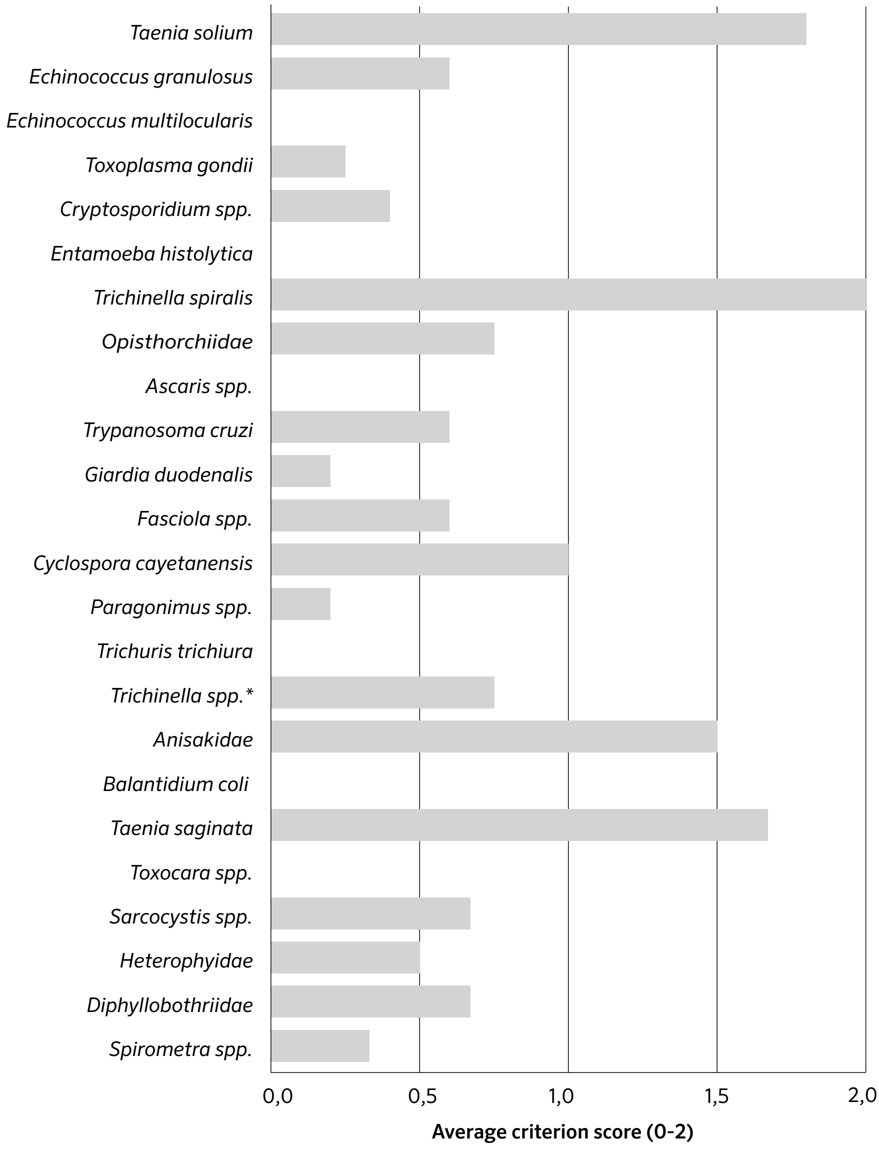

FIGURE 3. Relative ranking of international trade importance of parasites in primary food vehicles: average expert scores for Criterion 8 (based on Table 2; *Trichinella* spp.* includes all *Trichinella* species except *T. spiralis*)

several country reports as a class of organisms important to the country. These are probably countries that trade or consume fish extensively.

Conversely, parasites of concern in the overall ranking may not rank high as a trade concern. An example is *Toxoplasma gondii,* which might be prevalent in meat products but is microscopic and does not affect the appearance of the products, and there is no rapid, inexpensive, accurate test available. Therefore, for trade purposes, it would be ranked lower than the easily visible and detectable parasites.

3.3 SOCIO-ECONOMIC IMPACTS FOR THE RANKED PARASITES

The data analysed to rank parasites and generate Figure 2 are also used to produce Figure 4, which presents average scores for the socio-economic impact criterion. The figure indicates that there may be additional or separate socio-economic concerns not addressed in the overall ranking or in trade issues. An example of this is *Cyclospora cayetanensis*, which may require further investigation. It is probable that this reflects the known and on-going, socio-economic impacts on Guatemalan berry farmers, following the relatively extensive outbreaks of cyclosporiasis in North America during the 1990s. Outbreaks were primarily associated with berries imported from Guatemala.

Diseases caused by *Taenia solium* (ranked 1st) and *Echinococcus granulosus* and *E. multilocularis* (ranked 3rd and 4th, respectively) contribute to economic losses in human and animal populations in many parts of the world. They are considered preventable diseases that can be controlled or eliminated and should be prioritized (Carabin *et al*., 2005). Stigmatization and social isolation, attached to the occurrence of epilepsy caused by neurocysticercosis (*T. solium* infection), are examples of societal impact presented in the African Regional report, that are difficult to quantify but add to the socio-economic burden of this disease.

The parasites currently contemplated by the CCFH, T. *spiralis* and *T. saginata/C. bovis* were not considered important in terms of the socio-economic criterion.

3.4 CONCLUSIONS

The ranking exercise has provided a picture of the food-borne parasites of global importance today and has created a seemingly useful tool that is transparent and reproducible. The tool can be used with emphasis on different criteria and with or without weight factors. It is imperative that future use of this ranking tool and

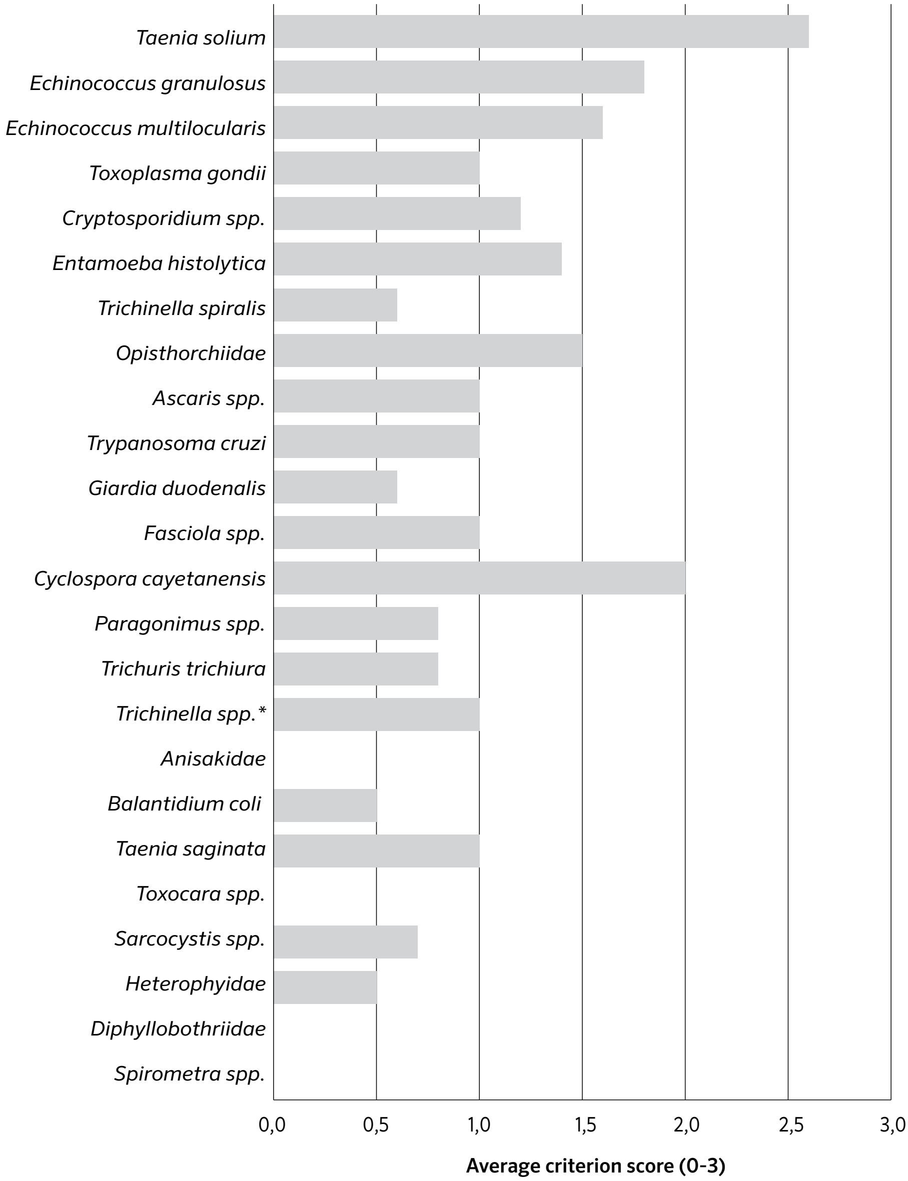

FIGURE 4. Relative ranking of socio-economic impacts of parasites to vulnerable communities: average expert scores for Criterion 9 (based on Table 2; *Trichinella* spp.* includes all *Trichinella* species except *T. spiralis*)

strategy be undertaken in a transparent manner. By using this approach, the results can be compared when the procedure is repeated.

The experts ranked the most important parasites by using multicriteria analysis during the meeting. The results shown in Figure 2 indicate that the method clearly defines those parasites that are highly ranked and those considered of lower rank. While *Taenia solium* clearly came out on top, there were less marked differences between the parasites that ranked second, third and fourth. Similarly those that ranked fifth, sixth and seventh are very close together, suggesting that the individual ranking is less important than the overall picture that the ranking provides in terms of food-borne parasites. As noted in the explanation of the weighting of the criteria, public health importance was the primary driver of ranking, with almost equal importance being given to illness and severity. This importance given to severity will have contributed to the high ranking of *Echinococcus granulosus*, ranked second, followed by *E. multilocularis*.

Toxoplasma gondii ranked fourth. The predominant disease burden of this parasite is confined mainly to substantial risks in pregnancy to the unborn, and in immunocompromised people (e.g. HIV/AIDS, transplantation patients). However, acquired toxoplasmosis also may contribute also an additional, substantial disease burden; many uncertainties still exist. The ranking order is affected by data availability; in the absence of data, or when data is limited, it is more difficult to categorize a parasite×food commodity. New data may influence ranking order. For example, the increasing number of papers linking toxoplasmosis with chronic illness (Havelaar *et al*., 2012), including mental illness (Henriquez *et al*., 2009) may push this parasite further up the ranking in the near future. Therefore, the parasite ranking list developed here should not be considered to be absolute or static; in order to remain current and fit for purpose, it must be updated periodically. The tool can be used also for prioritizing regional and national agendas for policy or research activities. There may be more specific data at national or regional level, as well as differing judgments on the importance of the various criteria, which could lead to a different ranking at a local level.

4

Risk management options for the higher ranked parasites

The identification of ranked parasites in Figure 2 is based not only on scientific evidence where available (including both published and unpublished data), but also on expert experience and opinion, and is weighted primarily by the public health concerns of the experts. The ranking of parasites by overall importance is the primary input to the risk managers in CCFH, who will then consider other issues relevant to management priorities and actions.

The ranking approach used in the expert meeting can be applied at the national level, where scoring may change, based on data availability and where weights may be placed on different criteria, based on the national situation or risk management issue.

Risk managers need to ensure that aspects other than the initial ranking by the experts that need to be considered in the decision-making process should also be evidence-based where possible, and done in a transparent manner. This section outlines some of these other considerations.

4.1 GENERAL RISK MANAGEMENT CONSIDERATIONS

It is important to recognize at all levels—global, regional and local—that there is a significant lack of information regarding food attribution for many parasitic diseases (Table 2). This is especially true for parasitic infections in which there may be a prolonged period (possibly many years) before symptoms appear (e.g. *Echinococcus* spp.) or those producing a chronic progression of disease (*Ascaris* spp., *Trypanosoma cruzi* and *Trichuris trichiura*). Food may be an important vehicle of transmission, but these parasites are not considered to be exclusively food-borne. For example, food may not be the primary transmission vehicle for *Echinococcus* spp.; however, the experts still considered these parasites as potential food-borne risks and advocate that further evidence be gathered to close this knowledge gap. *Echinococcus granulosus* and *E. multilocularis* ranked 2nd and 3rd, respectively, based largely on the potential severity of their associated diseases.

4.2 GENERIC RISK MANAGEMENT OPTIONS

As with other food-borne biological hazards, there are some generic good practices that are relevant for the control of food-borne parasites but are not necessarily unique to parasites. The importance of such practices may therefore already be captured in various existing risk-management documents. However, the recognition of parasites as being somewhat neglected warrants mention of any relevant control measures and management options.

4.2.1 Primary production and pre-harvest

While many of the parasites of concern are meat or fish-borne, for many others the entry into the food chain is via water or soil, or both. For example, *Ascaris, Cryptosporidium, Cyclospora, Echinococcus* and *Giardia* are essentially transmitted through the faecal-oral route, but may be transmitted by contaminated water during primary production of foods such as fresh produce. Thus, the primary production and pre-harvest stage of the food chain are critical in terms of control of numerous parasites, and it was considered that parasites may not be adequately considered in Good Agriculture Practices (GAPs). Some important considerations are highlighted here.

Parasites transmitted by the faecal-oral route

Given the importance of the faecal-oral route of transmission for some parasites, areas for cultivation of fresh produce, particularly for raw consumption, need to be assessed in terms of their susceptibility to faecal contamination, whether from run-off from wild animals, farm animals, domestic animals or and humans, and the necessary measures taken to manage the identified risk.

The importance of on-farm sanitation and hygiene in interrupting the life cycle of parasites and minimizing the opportunity for the faecal-oral route of transmission needs to be recognized, with appropriate installation and use of the relevant facilities promoted, e.g. functional on-farm latrines, and adequate hand-washing facilities.

The use of organic fertilizer, particularly on produce, should be monitored closely in order to ensure that it is composted adequately to destroy parasite transmission stages prior to use. However, it should be noted that the effectiveness of composting in destroying or inactivating parasites is uncertain, and should be considered a knowledge gap.

Zoonotic parasites

For those parasites with an indirect life cycle, special consideration must be given to breaking the cycle at the level of the intermediate host, such as snail (intermediate host) control in the case of trematode parasites in aquaculture.

The role of dogs and cats (domestic or feral) in transmission of certain parasites needs to be highlighted and farmers and other relevant stakeholders educated on good practices, e.g. no feeding of raw or untreated carcasses or offal of livestock and fish to domestic dogs and cats, or allowing wild canids and felids access to dead livestock, aborted foetuses, etc., and fish products; population control of semi-domesticated, stray or feral dogs and cats in close vicinity to the farm or aquaculture ponds.

Mass treatment of reservoir hosts, such as livestock, at frequent intervals in a sustainable fashion should ensure reduction in environmental contamination of infective stages. This applies to dogs in the case of echinococcosis by *Echinococcus granulosus*.

Water is an important vehicle for transmission for a number of food-borne parasites. Thus attention to water quality throughout the food-chain, from primary production through processing to consumption is very important.

Although not specific to primary production, monitoring and surveillance were considered to be important tools in the control of parasites, and for complete effectiveness may need to begin at the pre-harvest stage. For example, the ability to trace back infected animals at the abattoir level will allow identification of 'high risk' animals or fish populations or regions, and help allocation and targeting of resources for control. Furthermore, the ability to trace back fresh produce to the country, and even farm, of origin will allow identification of 'high risk' regions for subsequent risk management decisions. Monitoring and surveillance programmes can identify potentially emerging trends and risks for regional incursion (displaced forest animals or hosts in expanding urban environments).

4.2.2 Post-harvest

While post-harvest opportunities for control will be very dependent on the commodity of concern, it was considered that current Good Hygiene Practice (GHP), and HACCP plans for processing, etc., might not address parasitic hazards adequately.

In terms of processing, many parasite stages in meat and fish are susceptible to freezing as a process step and to controlled cooking at the process and consumer levels. However, the time×temperature combinations can be important, and in the cases of some parasites, such as *E. multilocularis* eggs, lower temperature domestic freezing may not be adequate. Irradiation can be an effective control measure and guidelines are available for its use in the control of *Toxoplasma* and *Trichinella*. Other control measures such as curing, salting, drying and high pressure processing need evaluation for specific parasites and food commodity contexts. Vacuum packing and chilling do not alter the viability of parasites in meat (e.g. *Toxoplasma* tissue cysts in meat).

4.2.3 Education

Education and awareness raising was identified as an important component of food-borne parasite control, and in some cases may be the only feasible option available. Education should be directed to actors throughout the food chain from farm and abattoir workers to food handlers (consumers and food retail outlets), and should address the gamut from good animal husbandry practices to hygiene and sanitation measures. In terms of consumer education there may also be a need to address specific high risk population groups. For consumers, especially those who are pregnant or immunocompromised (e.g. individuals with HIV/AIDS), advice on the preparation and consumption of high risk foods such as fresh produce and tubers, carrots etc., adequate cooking of meat and fish prior to consumption and the importance of hygiene, e.g. hand-washing, is critical.

4.3 SOME SPECIFIC CONSIDERATIONS FOR RISK MANAGEMENT

During the meeting specific consideration was given to the management of the eight top ranked parasites, and some of the important aspects for consideration by risk managers in deciding how to address these parasites. These considerations for *Taenia solium*, *Echinococcus granulosus*, *E. multilocularis, Toxoplasma gondii, Cryptosporidium* spp., *Entamoeba histolytica, Trichinella spiralis* and the Opisthorchiidae family are summarized in Table 4. Where they were identified, details of existing risk management texts or guidelines are provided. It should be noted that providing more specific input on the top eight ranked parasites was a function of the time available at the expert meeting rather than any technical consideration.

In addition, Table 5 provides some information on the global trade in those commodities identified as primary vehicles for the ranked parasites, thus providing an overview of their importance.

TABLE 4. Some specific risk management considerations relating to the top eight ranked parasites

Parasite	Hosts and main transmission routes – Food chains of concern	Severity of illness	Overarching factors for consideration in risk management	Examples of management options and challenges along the food chain			Examples of risk management texts and guidance
				On-farm	Post-harvest or processing	Retail and consumer	
Taenia solium	Two transmission routes: Undercooked pork – adult tapeworm infection (taeniosis) *T. solium* eggs – environment (e.g. via fresh produce) – larval stage infection (cysticercosis)	Taeniosis – a relatively benign disease. Cysticercosis a severe, potentially fatal, infection	Classified as eradicable but expensive and challenging to control. Human host means behaviour important in transmission Control strategies linked to whether a geographic area is categorized high or low risk	Vaccine use and chemo-therapeutic control in pigs. Good pig husbandry practices critical for sustainable control. Safe application of manure to control environmental contamination. Maintain high water quality.	Safe slaughter practices and an effective inspection system. Food handler education to target personal hygiene.	Consumer education on the role of humans in transmission. Consumption of raw produce in endemic areas is high risk. Cooking is effective.	FAO/WHO/OIE 2005.
Echinococcus granulosus	Fresh produce Sheep, cattle, goats and pigs are intermediate hosts	Severe clinical syndrome, cystic hydatid disease	Not complicated to control but requires coordination among relevant authorities. Effective treatment of dogs needs confinement and incineration of faeces for 2 days post treatment, then repeat in 45 days.	Elimination of the parasite in dogs. Education of farmers to minimize on-farm contamination and infection of animals. Control of water used, including fruit and vegetable production. Sheep and/ or dog vaccination may be a future option.	Effective inspection system to ensure GHP and GAP. Ability to trace back to farm. Keeping dogs away from potentially infected offal and from near abattoirs. *Echinococcus* eggs are not susceptible to freezing (except when core temperature of food is minus 80°C for 48 hrs or minus 70°C for 4 days).	Education of food handlers and consumers regarding food preparation and personal hygiene. *Echinococcus* eggs are not susceptible to freezing (except when core temperature of food is minus 80°C for 48 hrs or minus 70°C for 4 days).	WHO/OIE, 2001. OIE, 2005a. WHO, 2011.

Parasite	Hosts and main transmission routes – Food chains of concern	Severity of illness	Overarching factors for consideration in risk management	Examples of management options and challenges along the food chain			Examples of risk management texts and guidance
				On-farm	Post-harvest or processing	Retail and consumer	
Echinococcus multi-locularis	Fresh produce. New trend may be migration of the parasites with sylvatic incursion into residential areas.	Severe clinical syndrome, alveolar echino-coccosis	Far more challenging to control than *E. granulosus* given the predominance of a sylvatic cycle involving foxes and rodents.	Difficult to control in wildlife. Anthelminthic impregnated bait for foxes in peri-urban areas or around farms – may be difficult to sustain and also expensive.	*Echinococcus* eggs are not susceptible to freezing	Education of food handlers and consumers may be the most feasible form of control in endemic areas. Washing produce not be sufficient to remove parasites. *Echinococcus* eggs not susceptible to freezing (see above).	WHO/OIE, 2001. OIE, 2005a. WHO, 2011.
Toxoplasma gondii	Meat and offal from a range of animals (pigs, cattle, sheep, goats, game) may contain infectious tachyzoites. Oocysts can contaminate fresh produce and molluscan shellfish. Oocysts can be a source of on-farm infection for domestic animals.	Mild to moderate to severe, can cause abortions and congenital defects. May be linked to chronic mental and neurologic sequelae in adults.	Challenging to control because there are multiple possible vehicles. Non-food-borne infections complicated by the domestic "house" cat as a known parasite reservoir and source of infection.	Control feasible in housed or feedlot pigs and cattle (can be confirmed by serological testing - *Toxoplasma*-free designation) Not feasible in free range farmed animals. Vaccine available for sheep, but tissue cysts still present in meat.	Commercial freezers can kill tissue cysts in meat; domestic freezers or cooling under gas or vacuum may not be effective. Susceptible to pasteurization and cooking. Testing of meat & organ products not a viable option as cysts are small and randomly distributed. Lack of standardized methods means that fresh produce is not routinely tested for *T. gondii* oocysts.	Education of high-risk consumer groups is imperative; this includes pregnant women and immuno-compromised individuals.	Jones and Dubey, 2012. Kijlstra and Jongert, 2008.

Parasite	Hosts and main transmission routes – Food chains of concern	Severity of illness	Overarching factors for consideration in risk management	Examples of management options and challenges along the food chain			Examples of risk management texts and guidance
				On-farm	Post-harvest or processing	Retail and consumer	
Cryptosporidium spp.	Fresh produce, fruit juice, and milk. Likely entry into the food chain is by water and/or contamination by food handlers. The entire water system must be addressed, e.g. reservoir, piping, etc.	Mild to moderate to severe and chronic (immuno compromised)	Control measures for water quality throughout the water supply and food chain. Oocysts: (a) very resistant to chlorine, (b) detection methods do not assess viability, (c) can survive within, and be protected by, the stoma of fresh fruits and leafy vegetables.	Composting may be insufficient to inactivate oocysts. No housing of calves (and other livestock) in areas where produce is grown. Thorough washing of farm equipment, e.g. collection baskets. Dedicated use of equipment may help control.	Commercial tanks for washing produce can become contaminated. Transport vehicles, storage equipment & rooms important sources of cross-contamination. Susceptible to pasteurization and freezing. ISO developing a standard for detection in food. but expensive, efficiency may be low, small sample size may not account for heterogeneous distribution.	Consumer education is critical for HIV+ and other immunocompro-mised individuals, at risk for severe and chronic infections. Fresh produce may be high risk. Washing of fresh fruits and vegetables recommended but will not remove all oocysts.	ISO Standards. US-EPA Standards. UK-DWI Standards. Robertson and Fayer, 2012.
Entamoeba histolytica	Fresh produce. Largely water-borne and associated with food handlers. The cysts are sensitive to chlorine washes.	Mild to moderately severe. Diarrhoeal illness, liver abscess.	Diagnosis of *E. histolytica* requires specific tools to differentiate it from non-pathogenic *E. dispar* and *E. moshkovskii*.			Illnesses in the past have been linked to lack of hygiene during food preparation and consumption.	Theel and Pritt, 2012

Parasite	Hosts and main transmission routes – Food chains of concern	Severity of illness	Overarching factors for consideration in risk management	Examples of management options and challenges along the food chain			Examples of risk management texts and guidance
				On-farm	Post-harvest or processing	Retail and consumer	
Trichinella spiralis	Pork, horse and game meat.	Acute illness, low fatality rate	Trichinellosis occurs worldwide.	There are specific recommendations for *Trichinella*-free pig farming and national herd certification programmes.	Processing such as sausage making can spread one infected animal among many products, increasing the risk from a single contaminated animal.	Controlled in many countries, where present, by consumer education to cook pork thoroughly. Controlled by some religious and ethnic dietary restrictions.	FAO/WHO/OIE 2007. OIE, 2005b
Opisthorchiidae	Freshwater fish. The parasite occurs in fish in the wild and very rarely in those grown under commercial aquaculture. Multiple hosts, e.g. farm animals.	Severe infections, chronic sequelae, carcinogenic potential	It may be impossible to control the infection in wild-caught fish. Currently, of regional importance for Asia.	Discourage the feeding of unsterilized night soil (i.e. human faeces) to commercially farmed fish. Architecture and location of commercial ponds important to avoid contamination by faecal run-off.		During food preparation and consumption, Opisthorchiidae can be controlled by freezing and by thorough cooking.	FAO, 2012

TABLE 5. Commodity-trade volumes and monetary values of the primary food vehicles of transmission of the higher ranked parasites

Food Category	Trade volume (tonne) 2010 or 2009 (1)	Trade value (1000 US$) 2010 or 2009 (1)
Beef and veal	5 208 618	23 893 619
Pork	3 728 741	10 061 812
Goat meat	53 431	239 167
Sheep meat	962 169	5 110 599
Game/wild animal meat	55 198	477 096
Marine fish (edible product)	22 431 962	49 163 711
Freshwater fish (edible product)	3 627 385	17 797 345
Freshwater crustaceans (edible product)	31 818	226 837
Marine crustaceans (edible product)	2 947 344	19 591 627
Molluscan shellfish (bivalves) (edible product)	466 790	2 148 135
Berries	123 417	571 570
Fruit juice	2 707 796	3 527 824
Other fruits	1 955 370	1 660970
Vegetables, fresh	2 444 437	3 251 556

Sources: The information is based on that available for the year 2010 in the FAO Statistical database (FAOSTAT) as of 19 October 2012. (1) Information for fish, crustaceans and bivalves are for the year 2009, based on the latest available data from FAO Fisheries and Aquaculture Statistics Service, 2012.

5

Conclusions and recommendations

Providing risk managers with the information they need for decision-making is a critical element of food safety management. This meeting of technical experts was convened with the objective of providing information for globally important food-borne parasites. Given the breadth of the area of food-borne parasites, FAO and WHO concluded that addressing the task required a structured and transparent approach that made optimal use of existing information and was able to build on existing and relevant initiatives underway in both organizations. This led to the development of a multicriteria-based ranking tool, and challenged all the participants to use the available information and their expertise and apply it to the ranking exercise. While this initiative took substantial effort, the meeting concluded that the output, a transparent, reproducible and qualitative (with quantitative inputs) approach to ranking food-borne parasitic hazards of global importance and the application of that tool to produce a global ranking of food-borne hazards of concern was significant, and should provide CCFH with the requested overview of the parasite-commodity combinations of concern.

It is important to acknowledge that the present ranking is global and based on the state of knowledge and experience in 2012. Taking a global perspective, it is not expected that this would necessarily reflect parasite ranking at national level, where more precise information may be available and specific local conditions can be taken into consideration. For the current ranking, it is fully recognized that this could change as more research, data and information on food-borne parasites become available for further analysis and ranking refinement. Like many phases of risk analysis, this process is potentially most useful if it is replicated and updated on a continuous basis.

Furthermore, it is well recognized that initiatives such as the FERG initiative to assess the global burden of food-borne disease will in the medium term provide much more extensive information in terms of the public health importance and burden of food-borne diseases and be critical to furthering our understanding and knowledge. However, like any in-depth study, they are also resource and time intensive. In the meantime, ranking approaches such as the one described here allow the use of whatever information is available at a particular point in time to identify those parasites (or other hazards) of greatest concern and also to take into account aspects other than the public health element. The systematic and transparent approach means that they can be updated as new information comes on board and can be considered as one means of translating existing knowledge on food-borne parasites into a format that focuses the risk manager's attention.

The meeting concluded that food-borne parasites had not always received the attention they deserved based on their public health, trade and socio-economic importance. It was hoped that exercises such as this would serve to increase the awareness of food-borne parasites at a global level. Although it was recognized that the current meeting was aimed at providing advice to the CCFH, managing food-borne parasites is clearly a multidisciplinary task with a critical role for partners, not only those working with different parts of the food chain, but also in diverse disciplines addressing water, wildlife, the environment and more.

The meeting recognized that the ranking alone is not adequate for decision-making, and that the establishment of priorities by risk managers also requires consideration of other factors. Therefore, the experts aimed to provide additional information which could facilitate the decision-making process, including the primary food vehicles of concern for each of the parasites, knowledge on food attribution, and some information in relation to control of these parasites. An example of how these different elements could then be used by risk managers is presented in Annex 6. However, this report does not profess to be fully comprehensive, but rather raises awareness of certain aspects to be considered in the preliminary risk management phase. The existing materials, particularly for management of zoonotic parasites at the primary production stage, were fully acknowledged, and the meeting highlighted the importance of updating such texts. For example, the meeting recommended that the FAO/WHO/OIE guidelines for the surveillance, prevention and control of trichinellosis (2007) be periodically reviewed and updated to reflect technological advances.

The meeting also recognized that there are numerous knowledge gaps that hamper our efforts to control food-borne parasites, including the difficulty of attributing food or other vehicles for the transmission of parasite infection and illness. The importance of ongoing research into food-borne transmission of parasites was emphasized. One example is where recent studies suggest that, for *Toxoplasma gondii,* oocyst infection attributed to produce might be much more important than previously thought. While it was not within the scope of this meeting to address such aspects in detail, the meeting did recommend that if Codex decides to move forward with development of risk management guidance for specific parasites, then it should request more specific scientific input on the individual parasites.

References

Anderson, M., Jaykus, L.-A., Beaulieu, S. & Dennis, S. 2011. Pathogen- produce pair attribution risk ranking tool to prioritize fresh produce commodity and pathogen combinations for further evaluation (P^3ARRT). *Food Control*, 22: 1865–1872.

Boyer, K., Hill, D., Mui, E., Wroblewski, K., Karrison, T., Dubey, J.P., Sautter, M., Noble, A.G., Withers, S., Swisher, C., Heydemann, P., Hosten, T., Babiarz, J., Lee, D., Meier, P., McLeod, R. and the Toxoplasmosis Study Group. 2011. Unrecognized ingestion of *Toxoplasma gondii* oocysts leads to congenital toxoplasmosis and causes epidemics in North America. *Clinical and Infectious Diseases*, 53(11): 1081–1089.

Broglia, A. & Kapel, C. 2011. Changing dietary habits in a changing world: Emerging drivers for the transmission of food-borne parasitic zoonoses. *Veterinary Parasitology*, 182: 2–13.

Carabin, H., Budke, C.M., Cowan, L.D., Willingham III, A.L. & Torgerson, P.R. 2005. Methods for assessing the burden of parasitic zoonoses: echinococcosis and cysticercosis. *Trends in Parasitology*, 21(7): 327–333.

Carabin, H., Ndimubanzi, P.C., Budke, C.M., Nguyen, H., Qian, Y., Cowan, L.D., Stoner, J.A., Rainwater, E. & Dickey, M. 2011. Clinical manifestations associated with neurocysticercosis: a systematic review. *PLoS Neglected Tropical Diseases*, 5(5): e1152. (Online. doi: 10.1371/journal.pntd.0001152).

Cardoen, S., Van Huffel, X., Berkvens, D., Quoilin, S., Ducoffre, G., Saegerman, C., Speybroeck, N., Imberechts, H., Herman, L., Ducatelle, R. & Dierick, K. 2009. Evidence-based semiquantitative methodology for prioritization of foodborne zoonoses. *Foodborne Pathogens and Disease*, 6(9): 1083–1096.

CDC (Centers for Disease Control). No date [online]. Parasites Glossary. Available at http://www.cdc.gov/parasites/glossary.html#p Accessed 2013-07-03.

Davidson, R., Simard, M., Kutz, S.J., Kapel, C.M.O., Hamnes, I.S. & Robertson, L.J. 2011. Arctic parasitology: why should we care? *Trends in Parasitology*, 27(6): 238–244.

FAO. 2012. Assessment and management of seafood safety and quality – Current practices and emerging issues. Prepared by I. Karunasagar, L. Ababouch and J. Ryder. FAO Fisheries and Aquaculture Technical Paper, No. 574.

FAO/WHO/OIE. 2007. Guidelines for the surveillance, management, prevention and control of trichinellosis. Edited by J. Dupouy-Camet and K.D. Murrell. 119 p. Available at http://www.trichinellosis.org/uploads/FAO-WHO-OIE_Guidelines.pdf

Flisser, A., Craig, P.S. & Ito, A. 2011. Cysticercosis and taeniosis: *Taenia solium*, Taenia saginata, and Taenia asiatica. pp. 625–642, in: S.R. Palmer, Lord Soulsby, P.R. Torgerson and D.W.G. Brown (editors). *Zoonoses: Biology, Clinical Practice and Public Health Control*. Oxford University Press, New York, USA.

Fürst, T., Keiser, J. & Utzinger, J. 2012. Global burden of human food-borne trematodiasis: a systematic review and meta-analysis. *Lancet Infectious Diseases*, 12(3): 210–221.

Havelaar, A.H., van Rosse, F., Bucura, C., Toetenel, M.A., Haagsma, J.A., Kurowicka, D., Heesterbeek, J.H., Speybroeck, N., Langelaar, M.F., van der Giessen, J.W., Cooke, R.M. & Braks, M.A. 2010. Prioritizing emerging zoonoses in the Netherlands. *PLoS One*, 5(11): e13965. [Online doi: 10.1371/journal.pone.0013965.]

Havelaar, A.H., Haagsma, J.A., Mangen, M.J., Kemmeren, J.M., Verhoef, L.P., Vijgen, S.M., Wilson, M., Friesema, I.H., Kortbeek, L.M., van Duynhoven, Y.T. & van Pelt, W. 2012. Disease burden of foodborne pathogens in the Netherlands, 2009. *International Journal of Food Microbiology,* 156(3): 231–238.

Henriquez, S.A., Brett, R., Alexander, J., Pratt, J. & Roberts, C.W. 2009. Neuropsychiatric disease and *Toxoplasma gondii* infection. *Neuroimmunomodulation*, 16(2): 122–133.

Humblet, M.F., Vandeputte, S., Albert, A., Gosset, C., Kirschvink, N., Haubruge, E., Fecher-Bourgeois, F., Pastoret, P.P. & Saegerman, C. 2012. Multidisciplinary and evidence-based method for prioritizing diseases of food-producing animals and zoonoses. *Emerging Infectious Diseases*, 18(4). [Online. doi: 10.3201/eid1804.111151].

Jones, J.L. & Dubey, J.P. 2012. Food-borne toxoplasmosis. *Clinical Infectious Diseases*, 55(6): 845–851.

Kijlstra, A. & Jongert, E. 2008. Toxoplasma-safe meat: close to reality? Trends in Parasitology, 25(1): 18–22.

Krause, G. & and the Working Group on Prioritization at the Robert Koch Institute. 2008. How can infectious diseases be prioritized in public health? *EMBO Reports*, 9: S22–S27 [doi:10.1038/embor.2008.76]

López-Castillo, C.A., Díaz-Ramirez, J., Gómez-Marín, J.E. 2005. [Risk factors for *Toxoplasma gondii* infection in pregnant women in Armenia, Colombia] [In Spanish]. *Revista de salud publica (Bogota)*, 7(2): 180–190.

Macpherson, C.N.L. 2005. Human behaviour and the epidemiology of parasitic zoonoses. *International Journal for Parasitology*, 35(11-12): 1319–1331.

Mas-Coma, S., Valero, M.A. & Bargues, M.D. 2009. Climate change effects on trematodiases, with emphasis on zoonotic fascioliasis and schistosomiasis. *Veterinary Parasitology*, 163: 264–280.

Muñoz-Zanzi, C.A., Fry, P., Lesina, B. & Hill, D. 2010. *Toxoplasma gondii* oocyst-specific antibodies and source of infection. Emerging Infectious Diseases, 16(10): 1591–1593.

Ng, V. & Sargeant, J.M. 2012. A stakeholder-informed approach to the identification of criteria for the prioritization of zoonoses in Canada. *PLoS One*, 7(1): e29752. [Online. doi: 10.1371/journal.pone.0029752.]

OIE (World Organisation for Animal Health). 2005a. Terrestrial Animal Health Code, Chapter 8.4, Echinococcosis/Hydatidosis. See: http://www.oie.int/en/international-standard-setting/terrestrial-code/access-online/ Accessed 2013-07-06. Note that Chapter 8.4 is currently (July 2013) under revision, revising Chapter 8.4 for *E. Granulosu*, with a proposed new chapter for *E. multilocularis*.

OIE. 2005b. Terrestrial Animal Health Code, Chapter 8.13, *Trichinella* spp. See:http://www.oie.int/en/international-standard-setting/terrestrial-code/access-online/ Accessed 2013-07-06. Note that Chapter 8.13 is currently (July 2013) under revision.

Orlandi, P.A., Chu, D.-M.T., Bier, J.W. & Jackson, G.J. 2002. Parasites and the food supply. *Food Technology* 56(4): 72–81.

Polley, L. & Thompson, R.C.A. 2009. Parasite zoonoses and climate change: molecular tools for tracking shifting boundaries. *Trends in Parasitology*, 25(9): 285–291.

Robertson, L.J. & Fayer, R. 2012. Cryptosporidium. pp. 33–64 (Chapter 2), in: L.J. Robertson and H.V. Smith (editors). *Food-borne Protozoan Parasites*. Nova Scotia Publishers, Inc., Hauppauge, NY, USA.

Rohr, J.R., Dobson, A.P., Johnson, P.T.J., Kilpatrick, A.M., Paull, S.H., Raffel, T.R., Ruiz-Moreno, D.R. & Thomas, M,B. 2011. Frontiers in climate change – disease research. *Trends in Ecology and Evolution*, 26(6): 270–277.

Scallan, E., Hoekstra, R.M., Angulo, F.J., Tauxe, R.V., Widdowson, M.A., Roy, S.L., Jones, J.L. & Griffin, P.M. 2011. Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1): 7–15.

Slifko, T.R., Smith, H.V. & Rose, J.B. 2000. Emerging parasite zoonoses associated with water and food. *International Journal for Parasitology*, 30: 1379–1393.

Theel, E. & Pritt, B.S. 2012. *Balantidium coli and Entamoeba histolytica*. pp. 2–32 (Chapter 1) in: L.J. Robertson and H.V. Smith (editors). *Food-borne Protozoan Parasites*. Nova Scotia Publishers, Inc., Hauppauge, NY, USA.

WHO. 2011. Report of the WHO Informal Working Group on cystic and alveolar echinococcosis, surveillance, prevention and control, with the participation of FAO and OIE. 22–23 June, 2011. Department of Control of Neglected Tropical Diseases, WHO, Geneva, Switzerland. 20 p. Available at www.who.int/entity/neglected_diseases/diseases/echinococcosis/en/ Accessed 2013-07-04.

WHO/FAO/OIE. 2005. Guidelines for the surveillance, management, prevention and control of taeniosis/cysticercosis. Edited by K.D. Murrell and seven others. 99 p. Available at http://www.oie.int/doc/ged/d11245.pdf Accessed 2013-07-05.

WHO/OIE. 2001. WHO/OIE Manual on Echinococcosis in Humans and Animals: a Public Health Problem of Global Concern. Edited by J. Eckert, M.A. Gemmell, F.-X. Meslin and Z.S. Pawlowski. 285 p. Available at http://whqlibdoc.who.int/publications/2001/929044522X.pdf Accessed 2013-07-05.